UDC 778.534.2:
621.397.132

BBC

1969
THE QUEEN'S AWARD TO INDUSTRY

RESEARCH DEPARTMENT

REPORT

A technical appraisal of colour film in television

No. 1969/29

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

A TECHNICAL APPRAISAL OF COLOUR FILM IN TELEVISION

Research Department Report No. **1969/29**
UDC 778.534.2:
621.397.132

It uses SI units in accordance with B.S. document PD 5686.

C.B.B. Wood

D. Maurice
Head of Research Department

(PH-40)

Research Department Report No. **1969/29**

A TECHNICAL APPRAISAL OF COLOUR FILM IN TELEVISION

(PH-40)

September 1969

Research Department Report No. 1969/29
UDC 778.534.2:
621.397.132

A TECHNICAL APPRAISAL OF COLOUR FILM IN TELEVISION

This report is a transcript of a paper presented by the author at the International Technical Conference 'Film 69' held in London 21st to 27th June 1969.

SUMMARY

It may seem obvious that, when two imperfect reproduction media are taken in cascade, the end result will probably be inferior to either of them taken singly. It is certainly true that when colour television has for its input material a reproduction of the original scene by means of a colour motion-picture film, the picture quality reaching the television viewer is inferior to that which reaches him when a colour television camera views the scene directly. Regrettably the gap in technical quality between pictures from live television and those derived through film is widening rather than closing. The broadcasting engineer feels that despite frequent improvements, the colour television camera has still not reached the stage where its potentialities for resolution, sensitivity and colour fidelity have been fully exploited, whereas, on looking at colour motion-picture film, he is inclined to believe that improvements in this field are now coming very slowly.

1. QUALITY REQUIREMENTS

The colour motion-picture film processing laboratory probably does not find the requirements of the television broadcaster a very satisfying outlet. Television requires very few prints, frequently only one, and cannot afford to pay for the successive approximations by way of answer prints that are economic when the cost can be spread over a large number of release prints. Hence there is a tendency for the quality of colour grading in the television show print to be less good than that which the laboratories would like to achieve. In any case it seems hardly reasonable to expect the processing laboratories to work to such close tolerances that it is possible to take a series of clips from various laboratories all over the world, transmit them one after the other and achieve the shot to shot balance that is expected in a single roll from a single laboratory; yet this is the performance that television really needs.

2. CHOICE OF FILM GAUGE

The high cost of operating motion-picture photography for colour television, where the total expenditure is likely to be loaded on to one print used for a single showing, is such that broadcasters are being forced to consider the use of 16mm film even in applications where technical quality considerations show that 35mm operation under optimum conditions is only just satisfactory. The use of 16mm film results in a rather serious loss of resolution, visibly increases grain and brings a somewhat disturbing loss of picture steadiness. The saving in operating costs is, however, such that a lowering of standards of picture quality seems almost inevitable.

Even when the budget for a programme is sufficient to permit the use of 35mm film, the disadvantages of using film and television in cascade might cause a producer who is very conscious of technical picture quality to consider whether he would not prefer to use pictures electronically generated from the start, recording his material by means of a video tape machine. The equipment at present available for such an operation is much more expensive than that for filming and is bulkier, but the main objection will probably be the difficulty of editing the video tape recording. In the present state of the art this is a much more tedious process than editing film and involves equipment many times more expensive than that in the conventional film cutting room. Nevertheless the threat to film is there: hand-held colour television cameras and back-pack videotape recorders of unexceptionable performance are available and in service.

3. LOSSES IN PICTURE QUALITY

There will of course continue to be a large number of occasions when the initial recording of a scene to be reproduced on television is most conveniently made by means of a colour film but it is nevertheless salutory to consider the losses of technical quality that will be involved. It is proposed to consider losses only in a typical negative/positive system; some broadcasters are finding that the small exposure-latitude of the reversal film and the problems of maintaining colour fidelity through the duplicating process, more than offset the advantages of somewhat higher sensitivity and reduced grain of a reversal stock.

The accuracy with which the original scene may be reproduced is dependent, amongst other parameters, upon the relationship between the density of dyes and the light stimulus to which the film was exposed. The linearity with which a colour film is able to reproduce a grey scale can be regarded as its luminance characteristic; the fidelity of hue and saturation depend additionally on a combination of spectral sensitivity of the film, dye characteristics and the means used to view the film.

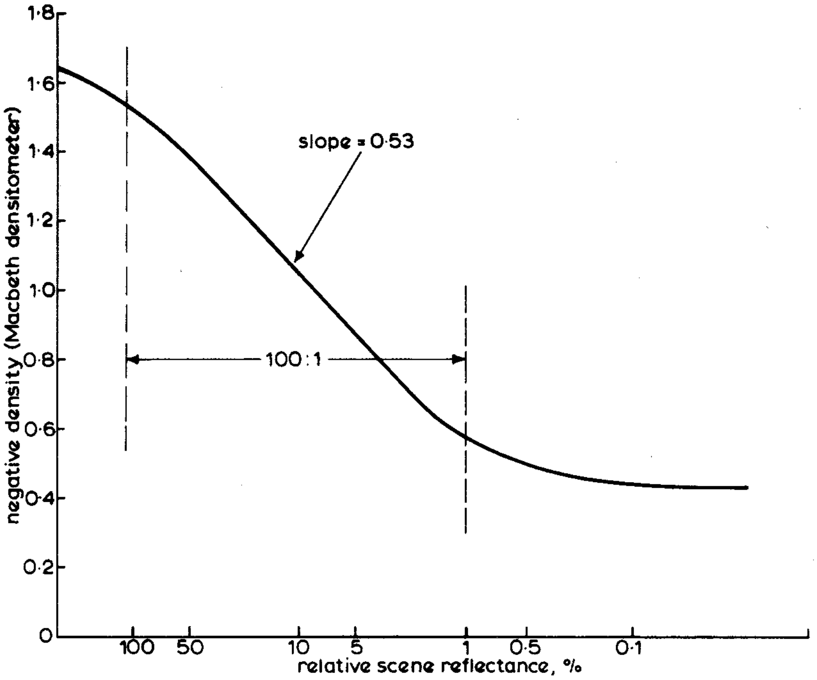

Fig. 1 - Negative density v. relative scene reflectance for a typical colour negative

3.1. Linearity of Luminance Characteristics

The measured relationship between relative scene reflectance and the density of a typical colour negative, exposed in a typical camera, is shown in Fig. 1. It will be seen that a scene contrast of about 100 : 1 is accomodated on a portion of the characteristic which corresponds substantially to a pure power law of gamma = 0·53. For scenes greater than 100 : 1 in contrast or in cases of over- or under-exposure, the recorded image departs from a pure power law. From the luminance transfer characteristic of a typical positive material, shown in Fig. 2, it will be seen that it barely approximates to a pure power law over sufficient contrast range to accomodate the negative. Optical flare in the printer and other factors influence the multiplication of the negative and positive characteristics so that the overall transfer from the original scene to the finished print is somewhat dependent on the quality of the printing. The measured transfer, from an original scene, through a negative exposed in a good quality camera, with a print made in a high grade printer, and reproduced in a modern telecine is shown in Fig. 3.

The ideal luminance characteristic is still the subject of some controversy.* A precise correspondence between scene luminance and that of the reproduced image is rarely practicable and probably not desirable. There will be at least a scaling of brightness values which may or may not be linear but in any case the film-plus-telecine combination should provide the optimum output signal characteristic. The transfer characteristic of the display tube in a colour television receiver follows quite closely that of a pure power law of exponent approximately 2·8: for overall linearity it is therefore necessary that the transmitted signal is related to the original scene luminance by a characteristic which gives a straight line when plotted on log-log paper and has a slope of 1/2·8. Where, as in Fig. 3, the transfer characteristic is a curve, rather than a straight line, the additional correction necessary to give a linear result or to achieve some preferred variation from this characteristic, is often so difficult and costly in signal-to-noise ratio that it is rarely attempted in practical telecines.

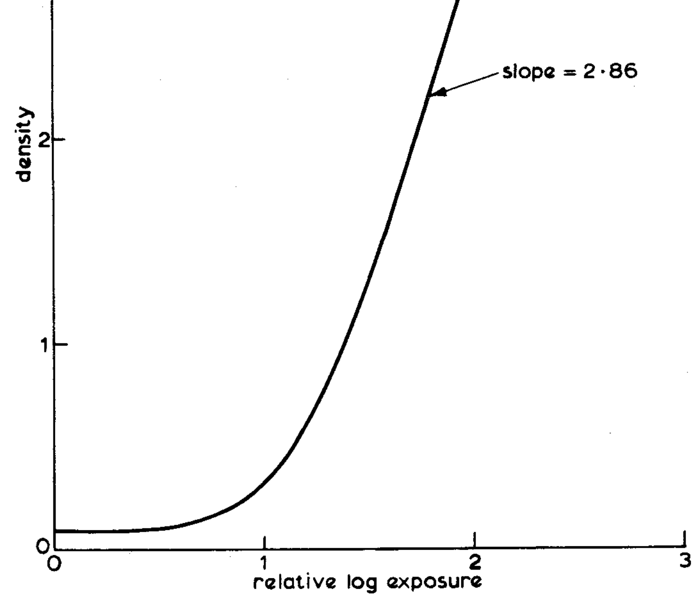

Fig. 2 - Positive density v. log exposure for a typical colour positive

* TOWNSEND, G.D. Film '69 — Paper — Transfer characteristics in the film-television process.

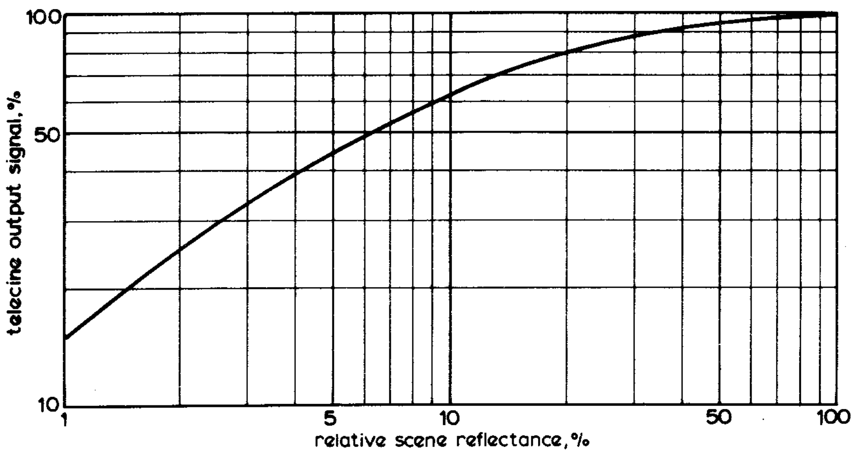

Fig. 3 - Telecine output signal v. relative scene reflectance (using a typical negative positive colour film process)

3.2. Resolution

The television engineer expresses resolution in terms of the loss of contrast in fine detail compared with the contrast of which the system is capable when it is shown a very coarse pattern of high and low luminance areas. The resolution of a 625-line, 50 fields per second television system is conveniently stated in terms of the depth of modulation of the signal related to scene detail of such spatial distribution that it corresponds to a video frequency of 5 MHz in the transmitted signal. The response to a coarse pattern producing, say 100 kHz in the video output, is taken to be the maximum.

Table 1 below shows some measured losses of depth of modulation in a system reproducing a 35mm negative/positive colour film process in a high grade flying spot colour telecine. Table 2 shows some measured results for a 16mm negative/positive colour film.

TABLE 1

Resolution of 5 MHz detail, 35mm film		
	Best Performance (Optimum Conditions throughout) decibels	Poor Performance (but not Fault Condition) decibels
10 x 25mm Zoom Lens at f3·5 (wide angle)	(−2	−4)
(narrow angle)	(−4	−6)
Negative Film	−3	−4
Printer	−1	−2
Positive Film	−2	−3
Telecine	−2	−3
Total Loss	−10 −12	−16 −18

In both cases shown in the tables above, the performance attributed to the telecine does not include the usual compensation applied in the electrical signals for losses of high frequency response due to the finite size of scanning apertures in the system. In setting up a colour telecine the operator makes some compromise between the sharpness of the reproduced picture and the random fluctuation noise which is visible as a disturbance of the picture. In the case of a 35mm flying-spot colour telecine the adjustment of aperture correction is usually such that there is a partial correction for the 10 decibels to 18 decibels loss of response at 5 MHz; the telecine thus corrects for some of the losses in the film. In the case of 16mm telecines the increase in noise limits the application of aperture correction and the telecine operator is obliged to effect a compromise which results in a less sharp picture which is also significantly noisier.

TABLE 2

Resolution of 5 MHz detail, 16mm film		
	Best Performance (Optimum Conditions throughout) decibels	Poor Performance (but not Fault Condition) decibels
10 x 12mm Zoom Lens at f2·2 (wide angle)	(−2	−4)
(narrow angle)	(−4	−6)
Negative Film	−8	−9
Printer	−3	−5
Positive Film	−6	−7
Telecine	−6	−8
Total Loss	−25 −27	−33 −35

3.3. Noise

The random fluctuation noise which accompanies all television signals arises at the point where light energy is transformed into electrical energy and also in stages of video signal amplification where the signal currents are very small. In a telecine apparatus which employs photoconductive camera tubes as the transducers from light energy to electrical signals, the noise added to the signal tends to be a constant regardless of the amplitude of the signal since it is determined mainly by the first stage of amplification.

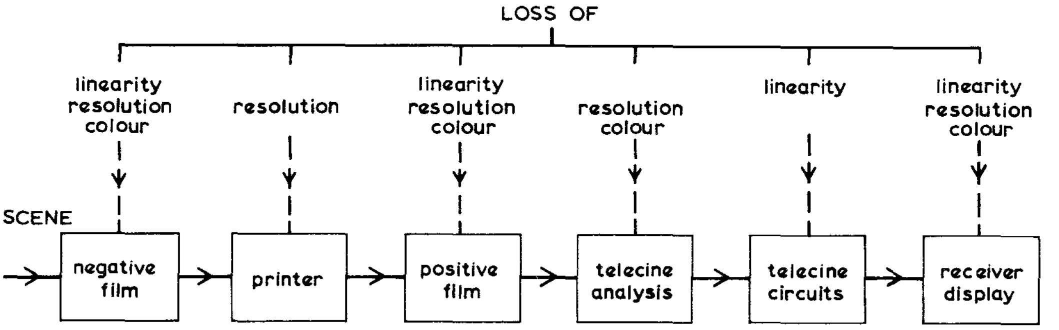

Fig. 4 - Sources of loss in the film-plus-television process

Furthermore the magnitude of the signal current is a function of the brightness of the image falling upon the photoconductive surface of the camera tube so that the signal-to-noise ratio can, at least in theory, be the same whether the film in use is 35mm or 16mm; it is merely necessary to adjust the power of the light source. Again in theory, the signal-to-noise ratio could be slightly better from a film scanner of this form than it is from a colour television studio camera since it is possible to create optimum illumination of each colour-separation image and allow all camera tubes to operate at maximum signal current.

In the flying spot telecine the signal-to-noise ratio is related to the area of the image being scanned and therefore a 16mm telecine is fundamentally about 6 decibels worse in signal-to-noise ratio than a 35mm telecine. In practice the 35mm machine does not fully achieve its advantage and the difference is rather less than this but neither flying spot telecine can surpass or even equal the signal-to-noise ratio performance of a modern colour television camera. Objective comparisons can be rather misleading since the distribution of noise throughout the grey scale from the flying spot scanner is different from that of a studio camera or a telecine using camera tubes. Subjectively a good 35mm colour telecine is more noisy than a good colour television camera but the disparity is small. Noise from a 16mm flying spot telecine is something of a problem.

4. THE OVERALL PROCESS: FILM PLUS TELEVISION

At each point at which the information concerning the scene is transferred from one form to another, losses and distortions are inevitable. The major stages in the process are shown diagrammatically in Fig. 4, and above each box representing a stage are shown the principal technical parameters of the picture liable to distortion. Approximately half the total chain as shown relates to the film process, but a high proportion of the total loss of linearity, resolution, and colour fidelity has often been incurred on reaching the stage at which a positive print is available. Some measured losses of linearity and resolution have already been stated in Fig. 3 and Tables 1 and 2. The results of a practical comparison between the colour fidelity of the overall process, Film-plus-Television (with electronic masking) and that of a live television system are shown in Fig. 5. The test colours

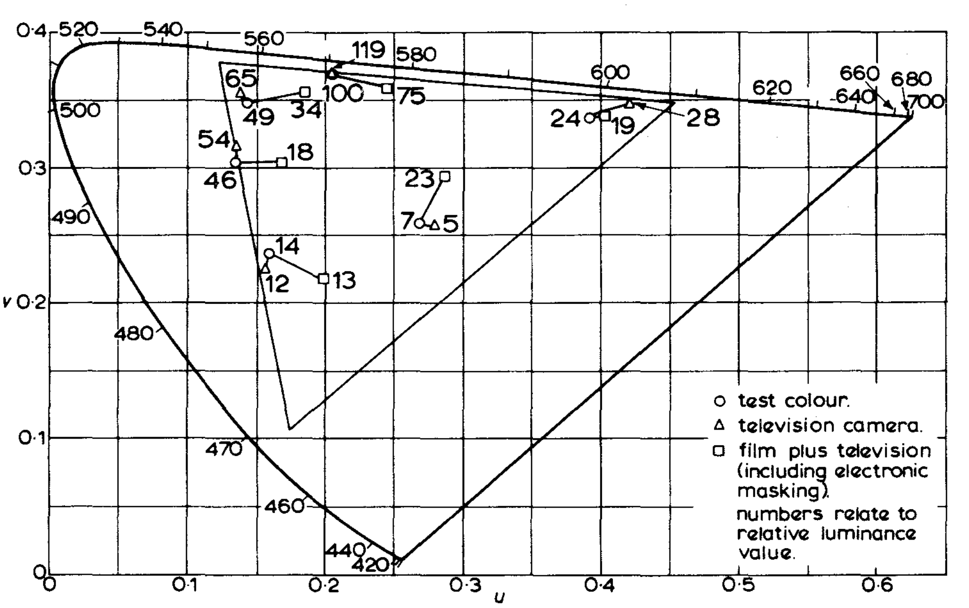

Fig. 5 - Comparison of the reproduction of test colours by a television camera and by a telecine (using a typical relative/positive colour film process with electronic masking)

are those of the Royal Television Society* which were photographed with a typical negative/positive motion picture process and the film was then reproduced in a telecine of outstanding performance. The colours in the reproduction are those given by the U.K. reference phosphors (BREMA 1968) in a display device of gamma 2·8. The same test colours were then viewed directly with a high quality four-tube colour camera and displayed with the same phosphors.

It is not intended in drawing these comparisons to convey the impression that the reproduction of colour film on television is a technical failure, giving unacceptable results. Very good results are frequently obtained, particularly when the film director has, in selecting and lighting his material, recognised the constraints imposed by the long process of many transfers, together with the reduced contrast-handling ability and different viewing conditions of television presentation. Nevertheless the motion picture film, as a pickup means for television, faces strong opposition from the all-electronically generated picture and, while it still has some advantages, it has lost the superiority of technical quality that it had in the early days of colour television.

5. A POSSIBLE REMEDY

The long chain of processes shown in Fig. 4 indicates that there could be opportunities to reduce the overall degradation of technical quality by arranging that distortions in one part of the chain are compensated to some extent by those in another part. Indeed the non-linearities of the negative and positive film characteristics are manipulated to give an acceptable, if not objectively accurate result. The next step leads to electronic masking, now an established practice, in which predictable losses of colour fidelity are compensated by a matrix of the primary television signals derived from scanning the film, thereby correcting much of the colour error before transmission. The disparity between the results in Fig. 5 would have been much greater had it not been for the assistance of electronic masking in the telecine.

* TOWNSEND, G.B. Coloured fabrics for use in colour television test scenes. Television Society Journal, Vol. 10, No. 7, pp. 208 – 212, July – September 1963.

Why not, however, eliminate some of the processes altogether? For optical projection in the cinema a positive print is clearly a necessity, but when the presentation is by television, in accordance with the system indicated in Fig. 4, the positive has no real purpose. It is nevertheless a major contributor to the losses of linearity, resolution, and colour fidelity. If the positive is eliminated, then of course the printer is also eliminated and with 16mm film the disappearance of these two will give an immediate 9 decibels to 12 decibels improvement in resolution at 5 MHz. Other benefits are equally important. The elimination of the non-linear characteristic of the positive print material makes possible the achievement of a much improved linearity of the overall process. A measured result is shown in Fig. 6. Furthermore the elimination of one stage of colour reproduction by means of film dyes will greatly reduce the corrections to be applied by electronic masking and improve the colour fidelity of the overall reproduction.

There is an opportunity, too, for the improvement of picture steadiness: elimination of the printer and the second set of film perforations of the positive print means that standardization of the camera register pin and the telecine pulldown reference perforation could have a real significance since the same piece of film base, with its inevitable perforation inaccuracies, now passes through both mechanisms.

The thought of discarding the colour positive print for broadcasting purposes is not new but television technology now seems to have reached the stage which will permit the successful inversion of the signals in the telecine to give a good-quality positive output from scanning a negative film. As in the case of electronic masking of a positive, logarithmic amplifiers are essential for accurate signal processing of negative films in the telecine but there are a number of differences in the technique for handling the signals from a colour negative film. A different form of TARIF* is required and although masking by means of coloured couplers is incorporated in many negatives, a substantial benefit may still be obtained by the application of electronic masking computed to suit the dye characteristics and spectral sensitivities of the negative material.

* WOOD, C.B.B., SANDERS, J.R. and GRIFFITHS, F.A. Electronic compensation for colour film processing errors. J.S.M.P.T.E., Vol. 74, No. 9, September 1965.

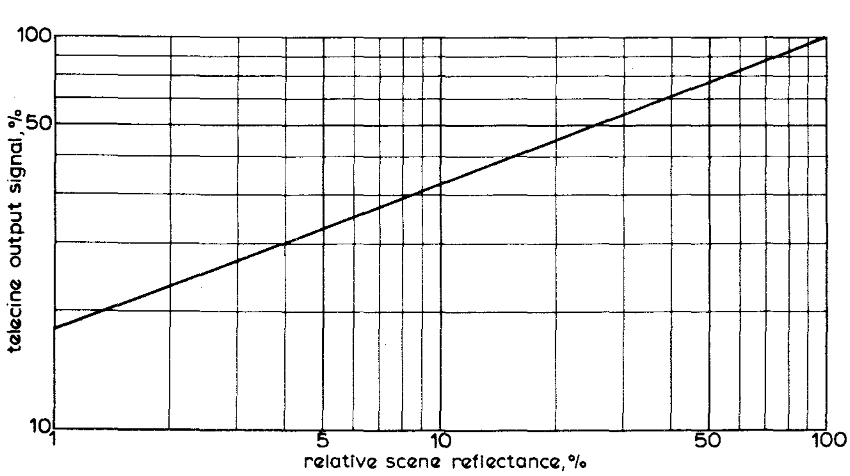

Fig. 6 - Telecine output signal v. scene reflectance (using negative colour film in telecine)

Fig. 6 shows that a satisfactory solution to the linearity problem has already been found and there are indications that the time may not be far off when an operational technique can be devised to use only colour negative film for television broadcasting purposes. Noise is the major outstanding difficulty as might be expected, since inversion and linearity-correction of the signals brings a large degree of amplification of the noise in the whites of the scene rather than there being the more usual greater concentration of noise in the blacks. Comparison of the relative merits of the flying spot and photoconductive scanners for noise is difficult. The fact that the noise of the flying spot scanner is proportional to the square root of the primary signal means, that after inversion, the distribution of noise throughout the grey scale is somewhat better than that from a photoconductive telecine and there is less disturbance by noise in the whites of the picture. The low absolute level of noise in the photoconductive scanner may, however, give it an advantage in the dark areas of the picture and it must be remembered that the use of negative materials with an integral mask will penalise the flying spot scanner whereas it can be compensated by modification of the light source in the photoconductive scanner. At the present state of the development of telecines it would seem that noise from a 35 mm flying spot telecine reproducing negative film is acceptable while that from a 16 mm scanner is marginal.

Table 3 below gives some measured signal-to-noise ratios for 35 mm and 16 mm unmasked negative films in a flying spot telecine compared with that for a photoconductive telecine in which steps had been taken to achieve optimum signal currents in all tubes. The measurements take into account the necessary aperture correction in each case and it is this which adversely affects the noise performance of the photoconductive scanner.

TABLE 3

Noise Level Relative to 100% Output Signal.
Decibels (negative film positive output signals)

	Scene luminance		
	100%	30%	1%
Flying spot 35 mm	−34	−38	−57
Telecine 16 mm	−30	−34	−53
Photoconductive Telecine 35 or 16 mm	−27	−35	−61

This shows clearly that noise performance is an area in which improvement is most needed. Visual sensitivity to noise is not uniform throughout the grey scale and it is possible to tolerate rather more noise in the whites of a displayed picture than in the dark greys, but it seems doubtful whether signal-to-noise ratios of less than 35 decibels at 100% scene luminance could be regarded as acceptable.

Plans for a comprehensive TARIF control and the introduction of an accurately-computed electronic masking process are well advanced.

6. OPERATIONAL TECHNIQUE

If it is assumed that the technical problems of satisfactorily scanning colour negatives are completely solved it still remains to consider how the process would be used to the best advantage. The thought that will have occurred to the reader is that the negative is a precious record, liable to irreparable damage and the possibility of it making repeated journeys to a telecine area cannot be contemplated. Furthermore, the negative is not timed or graded, so compensations for exposure or colour balance must be made in the telecine: this is likely to be a somewhat delicate process requiring skilful operation.

A solution to both these problems is to transfer the information from the negative film to positive signals recorded on videotape on a once-for-all-time basis. Comparatively little can go wrong with the reproduction of a videotape once it has been recorded satisfactorily and it is proposed that telecine operators would make the transfer from negative film to positive videotape under conditions where they were not under the tension of being 'on the air'. It is suggested that the procedure might be as follows:—

1. Shoot the colour negative in the usual way.
2. Make rushes in the usual way. (The broadcasters will probably use black and white rushes.)
3. Cut the colour negative.
4. Grade the colour negative scene by scene in a colour telecine head specially designed for still-frame scanning. This would be similar to one of the electronic colour-grading aids commercially available, designed to handle the film with the minimum of damage. It would differ from existing machines in that the scanning would be to broadcast television standards with colorimetry and electronic circuitry identical to that of the telecine which will eventually be used in the transfer from the negative film to videotape. Much of the apparatus might in fact be common to the two devices.
   Grading of the colour negative would be carried out by adjustment and recording of the TARIF setting necessary to give shot-to-shot colour matching and optimum colour balance. A punched paper tape record of the TARIF settings would be made for use when the transfer takes place as in (5) below.
5. Transfer the information from the colour negative film to a videotape by means of a specially modified telecine with pre-programmed, instantly switchable TARIF, using the information derived in (4) above.

This film-to-videotape transfer process would be carried out in a specially equipped transfer suite having facilities for the electronic addition of titles and other facilities normally provided as 'opticals' during the film processing stages. All subsequent replay and duplication would take place as videotape operations. By this operational technique the negative would receive no more handling than it does at present and it could be treated with equal freedom from hazard.

No doubt there would be a large number of operational difficulties to be overcome and it is not clear that there would be any substantial saving in costs since the personnel involved in the transfer operation would have to be highly skilled and, to get the very best out of the colour negative, would have to be unhurried. Storage of the videotape need not however be unduly protracted since the cut negative and its punched paper tape TARIF record would still exist in archives when the videotape was erased as soon as there was no apparent commitment for repeat of the programme.

7. CONCLUSION

It will be appreciated that much of this proposal is still speculative, although the technical facts stated are the result of experiment and measurement. It might well be found that the proposal is not operationally viable for a reason which is not at the moment apparent to the author, but a feasibility study is worthwhile.

It must be emphasised that the views expressed so far are those only of the Author and do not yet represent the views of the BBC.

8. ACKNOWLEDGEMENTS

The author is indebted to the Director of Engineering of the BBC for permission to publish this paper. He also wishes to acknowledge the fact that the experimental work, design of instrumentation and preparation of test results has been undertaken by his colleagues F.A. Bellis and F.A. Griffiths. It is hoped in the near future to publish a more comprehensive paper under joint authorship in which firmer conclusions will be drawn and details of the experiments devised by the author's colleagues are given.

SMW/JMP

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey